Yin, J. and Chen, W. and Li, Y. (2007) *Evolutionary computation enabled game theory based modelling of electricity market behaviours and applications.* In: IEEE Congress on Evolutionary Computation, 2007, 25-28 Sept 2007, Singapore.

http://eprints.gla.ac.uk/4829/

5th January 2009

Glasgow ePrints Service
https://eprints.gla.ac.uk

Evolutionary Computation Enabled Game Theory Based Modelling of Electricity Market Behaviours and Applications

Jin Yin[1], Wei Chen[2] and Yun Li[2]

[1] Energy and Resources Group, Deloitte Consulting
Oriental Plaza, 1 East Chang An Avenue, Beijing, 100738, China

[2] Department of Electronics and Electrical Engineering
University of Glasgow, Glasgow, G12 8LT, U.K.
Contact email: Y.Li@elec.gla.ac.uk

***Abstract*--The collapse of the Californian electricity market system in 2001 has highlighted urgency in research in intelligent electricity trading systems and strategies involving both suppliers and customs. In their trading systems, power generation companies under the New Electricity Trading Arrangement (NETA) of the UK are now developing gaming strategies. However, modelling of such "intelligent" market behaviours is extremely challenging, because traditional mathematical and computer modelling techniques cannot cope with the involvement of game theory. In this paper, evolutionary computation enabled modelling of such system is presented. Both competitive and cooperative game theory strategies are taken into account in evolving the intelligent model. The model then leads to intelligent trading strategy development and decision support. Experimental tests, verification and validation are carried out with various strategies, using different model scales and data published by NETA. Results show that evolutionary computation enabled game theory involved modelling and decision making provides an effective tool for NETA trading analysis, prediction and support.**

***KeyWords*--NETA, electricity market, game theory, evolutionary computation.**

1. INTRODUCTION

It is generally believed that opening the power industry to competition would benefit trading participants and improve economic efficiency. Since the 1980's, much effort has been made to restructure the traditional monopoly electricity industry. Whilst the details differ, the core of this reform involves the introduction of competition among electricity generators and suppliers through the creation of a deregulated electricity market. However, the California electricity trading market, which was regarded as a benchmark example of world-wide energy industries, shockingly collapsed after an energy crisis and, meanwhile, some generation companies in Californian made speculatively high profits [1]. Further, the cause to the biggest blackout in Eastern America recently is still unclear [2, 3].

Ideally, the market structure and management rules in an electricity market are expected to be well designed. However, the emergence of market power and collusion among energy companies has been drawing more attention to strategic gaming behaviour and market systems on global electricity trading.

In March 2001 the New Electricity Trading Arrangement (NETA) was implemented to operate power markets in England and Wales. The trading management mechanisms are still on trial operations for improvements. The improvements so far do not however alter the fact that there exist loopholes which can be exploited by market participants and could hence lead to collapse like the Californian electricity crisis of 2001. System models that reflect human intelligence in trading, market power and gaming strategies need to be developed and enhanced so as to avoid or significantly reduce disruptive trading operations and distorted market prices in NETA [4].

An intelligent decision-making and support technique, game theory, is often used in market practice. Game theory is a discipline concerned with how individuals make decisions when they are partly aware of what their action might affect each other and when each individual might take this into account. In general, there are three ways in developing intelligent and optimal trading strategies. The first one relays on estimations of the market clearing price (MCP) in the next trading period, which is relatively simple in principle. Based on estimates of the MCP, it is straightforward for a power supplier to determine its strategy by simply offering a price a little cheaper than the MCP. The second utilizes estimates of bidding behaviours of rival participants, which is more challenging. The third is game theory based and is the most sophisticated, involving market simulation and empirical methods [5].

A good market model therefore requires taking gaming behaviours into account, since gaming strategies are widely practised in trading systems for both decision-making and decision support. Modelling such a system is however extremely challenging, since conventional optimisation breaks down in dealing with non-numerical inferences. However, evolutionary computation (EC) with its a-posterior and coded search power can make such model building realisable.

In this paper, following analysis of intelligent market behaviours in Section 2, models are developed in Section 3 primarily to analyze the process of how power generators attempt to employ gaming strategies on NETA. Then these models are validated in Section 4 and their consequences are studied and possible market equilibria under such situations are searched for in Section 5, again

1-4244-1340-0/07/$25.00 ©2007 IEEE

Authorized licensed use limited to: UNIVERSITY OF GLASGOW. Downloaded on January 5, 2009 at 06:23 from IEEE Xplore. Restrictions apply.

using the power of EC. The research is formulated as both a decision support problem and an extra-numerical global optimisation problem. Finally, conclusions are drawn in Section 6.

2. MODELLING INTELLIGENT MARKET BEHAVIOURS

2.1 NETA Market Price Formulation

NETA is an electricity trading arrangement for bilateral trading between generators and suppliers. On NETA, there is high level of over-capacity in the market and hence market prices often gradually drop down. An objective behind generators' present gaming strategies is therefore to manipulate the market prices through reaching coalition among main generators to drive the marketplace to an oligopoly situation for a higher profit margin. In order to optimize the efficiency of these strategies, all sides involved need to improve in real-time and constantly search for optimal solutions during the trading procedure.

A basic structure of these models was published in the documentation of Office of Gas and Electricity Markets [5], [6], [7], [8] and [9]. Figure 1 demonstrates a representative structure of these models, based upon two sequential markets [6].

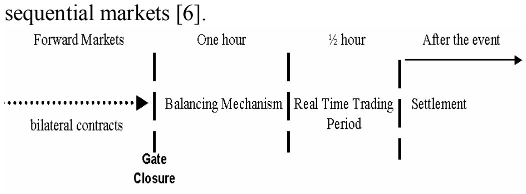

Figure 1: Trading stream on NETA

To explain this market mechanism, let PX stand for forward and spot markets, which evolve in response to the requirements of participants. This will allow bilateral contracts for electricity to be struck over timescales ranging from long term to on-the-day markets. The PX market clearing price is defined as:

$$PXP = f(Q_{\mathrm{SPX}}^{1},.., Q_{\mathrm{SPX}}^{i}, P_{\mathrm{SPX}}^{1},.., P_{\mathrm{SPX}}^{i};$$
$$P_{\mathrm{BPX}}^{1},.., P_{\mathrm{BPX}}^{j}, Q_{\mathrm{BPX}}^{1},.., Q_{\mathrm{BPX}}^{j}) \quad (1)$$

where i = 1 , 2, ...n represents the number of generators involved; j = 1 , 2, ... M represents the number of suppliers; Q_{SPX}^{i} and P_{SPX}^{i} are the quantity and price generator i wants to sell at PX, Q_{BPX}^{j} and P_{BPX}^{i} are the quantity and price supplier j wants to buy at PX.

After the PX, market participants submit a set of Offer-Bid pairs to a Balancing Mechanism (BM) to indicate the willingness of participants to operate at a level above or below their final bilateral contracts. The quantities contracted will be compared with the quantities generated or consumed to calculate the imbalances. If a plant is generating more than it has contracted or if a supplier is consuming less than it has contracted, transactions will be made at the System Sell Price (SSP), which is a weighted average of accepted Bids. If a plant is generating less than it has contracted or if a supplier is consuming more than it has contracted, one pays the bid prices, i.e., System Buy Price (SBP), which is a weighted average of accepted Offers.

The spread between the two prices is intended to provide a penalty for being out of balance. The SSP (SBP) is expected to be considerably lower (higher) than forward market price PXP [7], [8], [9] and [10].

2.2 Generator Gaming Strategies

The objective of generation companies' gaming strategy is to set up a collusion agreement among some main generators, at which these particular players keep withholding power output volumes during some specific periods, i.e. a number of weeks in the winter or summer, hence lead the whole marketplace to an oligopoly situation and drive up the market prices.

There are some uncertainties involved with this strategy that need be addressed by the agreement members, i.e,

(1) As NETA consists of two separate markets, i.e. PX and BM, how do they arrange output volumes between them to make the most profits on this strategy?
(2) For each generator, what should the optimal withheld output capacity and selling prices be?
(3) How do they keep coalition generators loyally to carry out the agreement?
(4) Is it likely that there exists equilibrium that collusive generators can make best profits meanwhile the markets trading can be kept in balance, i.e., does not collapse?

The market clearing prices, i.e. PXP, SSP and SBP, are results of interactions among all market players' bid/offer prices and output volumes. Because most of power volume trading is carried out on PX, imbalance penalties in BM are much higher than PX clearing prices. Therefore the core of gaming generators' strategies is to withhold their output volumes on PX and to make the supply/demand unbalanced on this market. As consequence of maintaining this strategy, power suppliers will be driven to BM and purchase the shortfall with imbalance charges.

This sort of collusion among gaming generators is termed as "cooperative strategy" in game theory. As its legality might be doubted, the agreement exists only in verbal form, which is actually tolerated and even encouraged by a number of European countries [11].

When evolving an intelligent model, the following features of the market need to be considered:

(1) Trading participants include n electricity generators (sellers), as some generation companies that sell energy in the market, m power suppliers (buyers), as energy service companies, i.e. power transmission companies that buy electricity to serve end-users, and the System Operator (SO) who operates the markets.
(2) Double-side bidding mechanism is adopted following the fact on NETA.
(3) Colluded generators are concerned about the expected payoff in the long run rather than the pay-off in a particular round of auction.
(4) System Operator broadcasts 2-14 day-ahead demand forecast and provides real time

Authorized licensed use limited to: UNIVERSITY OF GLASGOW. Downloaded on January 5, 2009 at 06:23 from IEEE Xplore. Restrictions apply.

information and offers made and accepted, as the same case on NETA.

(5) For simplicity, the demand elasticity, transmission constraints and loss are ignored when SO matches selling and buying quantity.

The following cooperative behaviours also need to be taken into account:

(1) Each member of the agreement withholds a portion of its total capacity, as variable X, expressed as a percentage of its total generation capacity. The range of X is assumed to be from 10% to 40%. Then the remaining volume Q_{smax}^{i} . (1-X), is traded into the PX.

(2) After the suppliers are driven to BM and have to submit bids for getting extra supply with paying SBP, the gaming generators need to provide offers to BM to meet the shortfall demand and determine how much volume should be taken from the withheld volume Q_{smax}^{i} . X to trade in BM. Given the part taken from Q_{smax}^{i} . X is Y, expressed as a percentage from 0-100%.

(3) The last part of the cooperative strategies is to optimise the trading on forward markets. Because the state of suppliers is no longer superior as before when the market is under an oligopolistic condition, generators can improve their selling curves to drive up the market prices as high as the suppliers could accept under PX.

In building the market model, each generator is characterized by three sets of parameters:

(1) Fixed electricity generation parameters, i.e. maximal generation capacity Q_{smax}^{i}, marginal cost P_{ma}^{i}, etc.

(2) Strategic variables: X being generator i's portion parameter on PX, P_{SPX}^{i} being the price that generator i wants to sell on PX, Q_{SPX}^{i} being the quantity that generator i wants to sell on PX, portfolio instrument l expressed as a percentage of its total generation capacity, BM Offer price P_{O}^{i} and Q_{SBM}^{i} being the quantity generator i wants to sell at BM. Their relationship is formulated as:

$$Q_{\text{smax}}^{i} \cdot l = Q_{\text{SPX}}^{i} + Q_{\text{SBM}}^{i} \tag{2}$$

(3) Collusion parameters: P_{TR}, T, Q_{comp} and $Q_{\text{coop.}}$

There are two types of gaming generators. One follows a strategy called "opportunistic collusion" whereby generators withhold capacity from the market only when they perceive an "opportunity" to raise profits by doing so exists. Opportunistic collusion might result in a generator setting aside a portion of their capacity and deciding for each hour whether or not to offer that capacity to the market depending on expectations of raising profits. This is different from the other type, suggesting that generators should "always" withhold a portion in anticipation of an agreement. The second kind is named "loyal co-operator".

For making the agreement more efficient, a more extreme management-enforcement is utilized to constrain the agreement members by "loyal co-operator". In this application, a well-known game theory strategy, "trigger price strategies" [12], is employed to enhance this agreement. On a trigger price strategy, collusive generators make inferences about any members in this agreement from the observation of market price P_{PX}. If the price remains above some critical value – the trigger value – then the generators will infer no cheating on the coalition and will maintain a cooperative output level. If the price falls below the trigger, then some punishment must be imposed on the cheater(s).

Trigger price strategy depends on four parameters, P_{TR}, T, Q_{comp} and Q_{coop}, where P_{TR} is the trigger price, T is the number of time periods the punishment will last, Q_{comp} is the competitive output given 100% generation volume Q_{smax}^{i}, and Q_{coop} is the cooperative output given Q_{smax}^{i} . (1-X).

There exist other generators who do not join the collusion and each of them independently trades all of its generation volume on PX. As a result, the state of such generators is inferior to suppliers because the latter have enough choices to select generators with low selling prices to make contracts, and hence all suppliers' demand is theoretically satisfied. The contracted prices, as forward markets prices, could be as low as what suppliers could accept. Consequently, generators can only sell out parts of their total volumes at P_{PX} level.

2.3 Supplier Gaming Strategies

For suppliers, the dual cash out prices of BM are intended to discourage market participants from being out of balance because the penalty for contracting at less than actual demand can be extremely high. Suppliers have therefore responded to NETA imbalance prices by over-contracting to reduce exposure to SBP [13]. The cost of over-contracting can be viewed as an insurance premium that reduces exposure to the potentially high risks of being short.

Each supplier's objective is to optimize its contract position, as well as trading prices, to minimize the cost of contracting in order to maximize total daily profits.

The strategy of each supplier j, is characterized as following [14]:

$$C_{\text{L}} = \sum_{r}^{48} -PXP^{r} \cdot Q_{\text{D}}^{r} \tag{3}$$

where C_{L} is the marginal cost of supplier j, r is the settlement period number, PXP is the PX clearing price and Q_{D}^{j} is the actual demand at settlement period r:

$$C_{\text{S}} = \sum_{r}^{48} (PXP^{r} \cdot Q_{\text{C}}^{r} - \text{Max}[0, Q_{\text{C}}^{r} - Q_{\text{D}}^{r}] \cdot SSP^{r} + \text{Max}[0, Q_{\text{D}}^{r} - Q_{\text{C}}^{r}] \cdot SBP^{r}) \tag{4}$$

where C_{S} is the contracted cost of supplier j, Q_{C}^{j} is the contracted volume at settlement period r on PX.

A percentage premium for supplier's strategy is derived from $(C_{\text{S}}/ C_{\text{L}})$; the lower the premium the more efficient the strategy.

3. INTELLIGENT AGENTS AND MODELLING

Based on the analysis in the previous section, a basic model structure involving thermal, nuclear, combined cycle gas turbine (CCGT) and renewable plants is presented in Figure 2. Cooperative generators have many strategic variables, i.e. P_{SPX}^{i}, Q_{SPX}^{i}, l, X, P_{O}^{i}, Q_{SBM}^{i}, that need to be optimized. Further competitive generators face

Authorized licensed use limited to: UNIVERSITY OF GLASGOW. Downloaded on January 5, 2009 at 06:23 from IEEE Xplore. Restrictions apply.

a dilemma. On one hand, they have to make their selling prices appropriately low to win contracts. On the other, they need to offer selling prices higher than individual marginal cost P_{ma}^{i} to cover the production cost. On the other side of this competition, supply companies also face the evaluation and optimization problems expressed in equations (3) and (4).

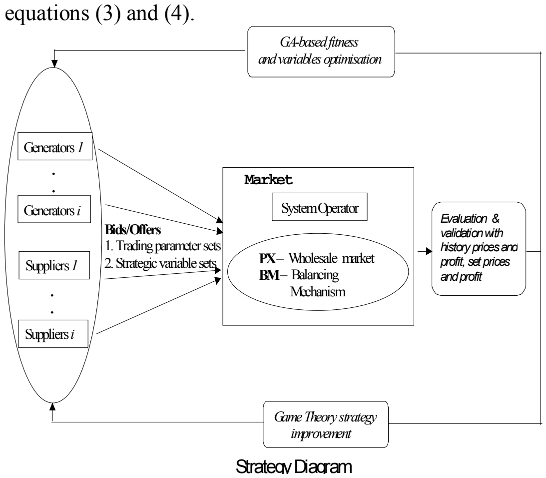

Figure 2: Structure of a market model

The major task here is to model generators and suppliers as decision-making participants. Many performance variables in the power market trading strategy development do not present accurate measurements. Conventional mathematical models are hence inadequate here. Many incommensurable and competing objectives require meeting before any solution is considered adequate. However, these can be handled by a genetic algorithm (GA), which is a representative of search, machine learning and optimisation techniques that are non-deterministic and a posterior. GA employs coding and hence deals with non-numerical variables involved in game theory model. An organism's genetic code is its position in solution space while its survival in its environment and its number of offspring indicates probabilistically the degree to which it meets its objectives. It is powerful techniques in the search for global optimal solutions and hence a GA is employed to solve these game theory activated extra-numerical search and optimization problems.

Strategic variables and parameters of market players are mapped into GA chromosomes. Each auction round represents a generation. The GA population is divided into sellers and buyers. Information is exchanged solely within each type of traders. There is no information exchange between buyers and sellers other than the amount of profit they made known. The fitness of each trader is proportional to the profit made in the auction round and is recalculated every round. Once a population of individuals with assigned fitness values arises, the next step is to preferentially select a subset of individuals that should survive into the next generation. Figure 3 shows the search and evaluation process and Table 1 lists GA parameters used.

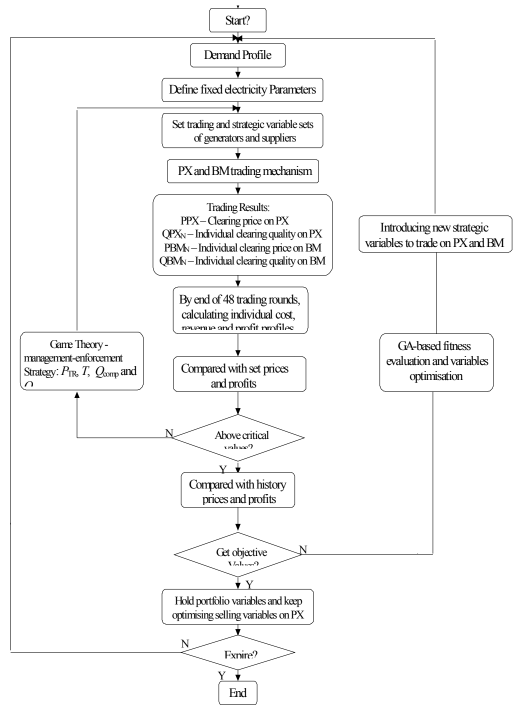

Figure 3: Evolving intelligent gaming models

Table 1 GA parameters in evolutionary model building

Input Specifications	Values
Number of Generations (Suppliers)	480
Populations size (Suppliers)	20
Chromosome Length (Suppliers)	9
Number of Generations (Generators)	480
Populations size (Generators)	20
Chromosome Length (Generators)	15
Selection mechanism	Tournament
Crossover	70% uniform
Mutation	0.1%

Here, the tournament selection scheme is employed, based on group competitions. The population is divided into subgroups, which can be any size, or members with the best fitness among the subgroups get selected. The uniform crossover method is used in which offspring individuals are created from a randomly generated uniform bit mask. An elitism technique is also implemented.

It is worth noting that bounded rational agents are built to learn about their environment and improve their trading behaviour with experience. However, at the same time the agents' behaviour should not be too non-rational (some lower bounds were imposed on the agents' level of rationality). It has to be made sure that the agents do not choose completely unreasonable actions, even in the early stages of the learning process.

In order to avoid inconsistent behaviour during the learning process, some lower bounds of rationality are imposed through operational rules, including:

Authorized licensed use limited to: UNIVERSITY OF GLASGOW. Downloaded on January 5, 2009 at 06:23 from IEEE Xplore. Restrictions apply.

(1) Adaptive expectation: Never bid (or offer) above (or below) the previous SBP (or SSP).
(2) Avoidable cost: Never pay more than the marginal cost for "speculative" decrement.

4. MODEL ANALYSIS AND VERIFICATION

Once NETA market is successfully modelled, the model confirms that generators have an incentive to withhold capacity from the market. The model also reveals that there are two types of gaming generators. The first is the classical "tacit collusion" that occurs in static repeated withholding output capacity, where the object is for all players to learn that they can always make excess profits if they withhold amount of capacity from the market. This kind is referred to "loyal co-operators", suggesting that these generators should "always" withhold a portion in anticipation of an agreement.

The second type asserts, however, that it is not always profitable to withhold capacity from the market, since the opportunity for raising profits does not always exist due to internalities and externalities, such as collaborative generators breaking the agreement, the demand bid, imbalance prices, etc. We refer this phenomenon to "opportunistic tacit collusion" to distinguish it from the classical "tacit collusion". These generators follow an "opportunistic collusion" strategy whereby generators withhold capacity from the market only when they perceive an "opportunity" to raise profits by doing so exists. Opportunistic collusion might result in a generator setting aside a portion of their capacity and deciding for each trading round whether or not to offer that capacity to the market depending on expectations of raising profits. Once this is learned suppliers "tacitly collude" to sustain high market prices.

For the "opportunistic collusive" generators, it is difficult to judge an "opportunity" to get more profits by estimating possible profit with cooperative strategy. Because in a certain market environment where a wide number of market participants are trading interactively, there are uncertainties and it is unlikely to precisely predict all participants' future moves and trading consequence. Nevertheless, the market clearing price in PX, *PXP*, and individual generators' capacity used in both of PX and BM, are introduced as the reference for the "opportunistic collusive" generators to decide whether or not to join the coalition agreement and withhold capacity from the market.

4.1 Small-Scale Model Simulation

In order to gain a better view of the effects of gaming trading strategies on NETA, the first application experiment is carried out based on a small scale model. The total available generation capacity is assumed as 33.3GW in this experiment. The number of generators, m, is assumed to 5, and suppliers', n, is assumed to 4 in this experiment. The total demand is set as 25 GW, therefore the individual maximal demand Q_{dmax}^{i}, of each supplier is set as 6250MW. These experiments are based on the standard daily demand profile in November 2004, published by NETA and shown in Figure 4.

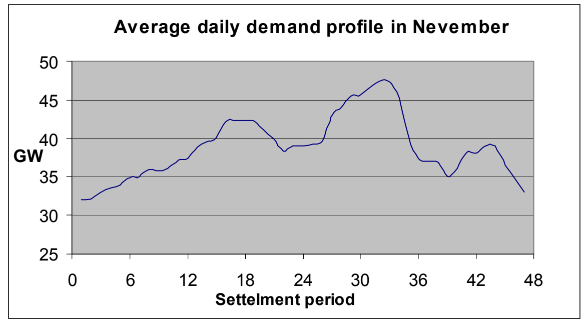

Figure 4: Standard daily demand profile in November [15]

The generation system self-parameter of this model is demonstrated in Table 2:

Table 2 Generators' system self-parameters

Type of generation plants	Nuclear	Combined cycle Gas turbine (CCGT)	Large coal	Gas turbines	Oil
Marginal generation cost (£/MWH)	24.50	9.72	33.23	66.95	87.91
Maximal generation capacity (MW)	6600	6600	6600	6600	6600

The wholesale market clearing price PXP, imbalanced settlement prices System Buy Price SBP and System Sell Price SSP are major model outputs to assess the performance of market players' different strategies. They are presented and evaluated as following figures.

Figure 5 demonstrates the mean daily Power Exchange market prices in a week:

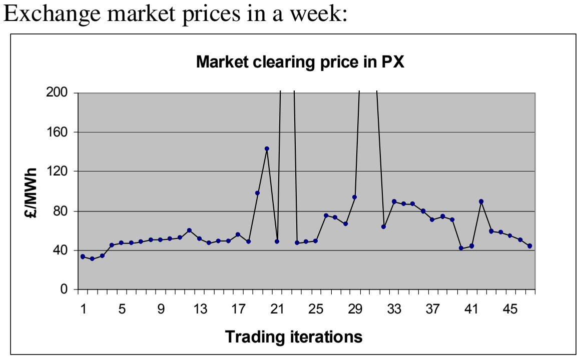

Figure 5: Mean daily market clearing price in PX

Figure 6 demonstrates the mean daily price curves of the imbalanced settlement prices SSP and SBP in a week:

Authorized licensed use limited to: UNIVERSITY OF GLASGOW. Downloaded on January 5, 2009 at 06:23 from IEEE Xplore. Restrictions apply.

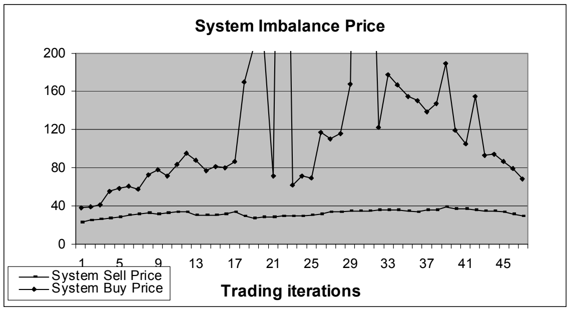

Figure 6: Mean daily System Imbalance Price

4.2 Large-Scale Model Simulation

In order to compare the effects of market player strategies under different market circumstance, the second application experiment is taken on a large-scale model which is comparably similar to the NETA market. The total available capacity is set same as the experimental model at which the non-cooperative strategy is employed. The number of generators, *m*, is assumed to 15, and suppliers', *n*, is assumed to 10 in this experiment as well. The generators of the same type are assumed to have similar marginal costs and generation capacity. The generators' system parameters, i.e. estimated marginal generation costs P_{mc}^{i}, assumed maximal generation capacity Q_{smax}^{i}, of each generator on each generation type are presented in Table 3 below. The total available generation capacity is set as 66.7GW. Oppositely, the maximal market demand is 50GW, which is same as the market scale of the NETA, so that the average maximal demand Q_{dmax}^{i}, of each supplier is 1125MW. The ratio of maximal market demand to total available generation capacity is set as 0.75, following the real situation in NETA. The large-scale experiments are based on the same winter daily demand profile introduced in the previous experiment. The generation system self-parameters show as Table 3:

Table 3 Generators' system self-parameters

Type of generation plants	**Nuclear**	**Combined cycle Gas turbine (CCGT)**	**Large Coal**	**Gas Turbines**	**Oil**
Marginal generation cost (£/MWH)	24.50	9.72	33.23	66.95	87.91
Maximal generation capacity (MW)	4450	4450	4450	4450	4450

The model major outputs market clearing price PXP, imbalanced settlement prices System Buy Price SBP and System Sell Price SSP are presented and evaluated as following figures.

Figure 7 shows the mean daily market clearing price in PX in a week:

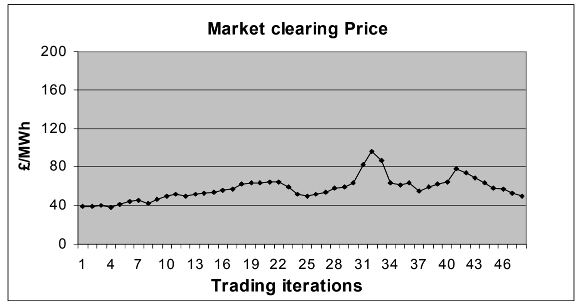

Figure 7: Mean daily market clearing price in PX

Figure 8 shows the mean daily System Imbalance Price in a week:

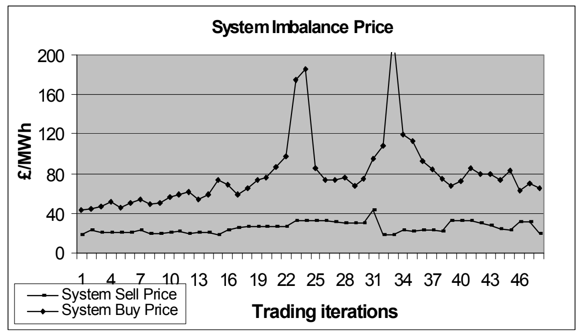

Figure 8: Mean daily System Imbalance Price

5. APPLICATIONS OF THE MODEL

A set of tests are carried out in developing different gaming strategies using the model. The estimates used are consistent with those used in published studies on the U.K. electricity market, i.e. actual demand profiles, generation and supply parameters. There are sorts of power generation concerned in this model. After the computing is finished, output sets are evaluated to find out the market states and consequence of which strategic generators maintain gaming behaviours.

5.1 Competitive strategy

Test results show that market prices on PX are kept on a quite low level and an equilibrium state is achieved when all generation companies are independently trade without any collusion. Figure 10 displays this tendency based on published data.

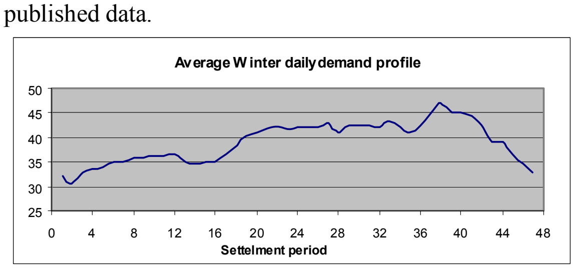

Figure 9: Average winter demand profile

Authorized licensed use limited to: UNIVERSITY OF GLASGOW. Downloaded on January 5, 2009 at 06:23 from IEEE Xplore. Restrictions apply.

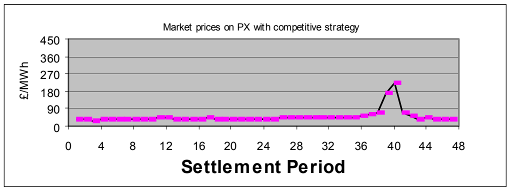

Figure 10: Trend of P*px* without gaming strategy

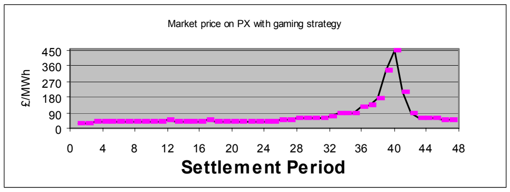

Figure 11: Trend of P*px* with gaming strategy

5.2 Cooperative Strategy

On the second set generators are divided into two groups: some adopt competitive strategy with never joining coalition agreement; the others are gaming players.

Figure 11 presents that the market prices on PX are pushed up to a significantly high level and a serious price spike is caused about 20 times than average marginal cost. This result is still far lower than the spike happened in California energy crisis that was 40 times than average marginal cost. Programming results demonstrate that when half of main generators, who use "opportunistic collusion" strategy at trading, quit this collusive agreement sometimes when they find that they can make more profits if they are outside the coalition, market price cannot be pushed over £500/MWh.

The difference between the profit of CCGT(Combined cycle gas turbine) generator with gaming strategy and the one without strategy is showed in Figure 12.

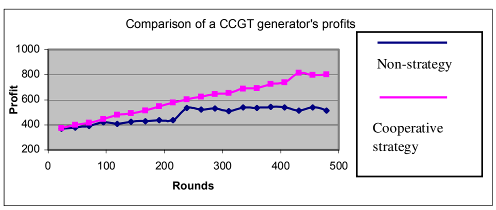

Figure 12: Comparison of a CCGT generator's profits

Another method to evaluate the two strategies is the "percentage premium".

Percentage premium = Imbalance penalty/Profit (5)

To avoid the risk of being penalised at the imbalance settlement stage, generators over contract as an insurance against plant outage, running their sets at below their optimum efficiency, whilst suppliers ensure that their contracts exceed their highest estimate of demand, insurance against the symmetric penalties. This over-contracting strategy is expressed as over-contracting premium on functions (3) and (4). Figure 13 and 14 present the comparison between the over-contracting premium for competitive strategy and gaming strategy, respectively for a CCGT generator and a supplier. Figure 15 and 16 illustrate the comparison of the unbalancing volumes and prices for this particular generator.

In Figure 8 shows that the CCGT generator pays much less penalty when gaming strategy is employed.

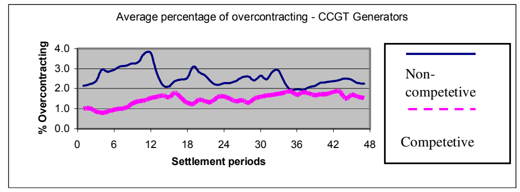

Figure 13: Comparison of CCGT's percentage over contraction

To evaluate efficiency of this strategy, model outputs are compared with results of another strategy [16]. Figure 17 and 18 demonstrate the difference.

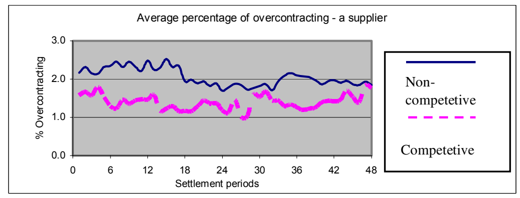

Figure 14: Comparison of a supplier's percentage over contraction

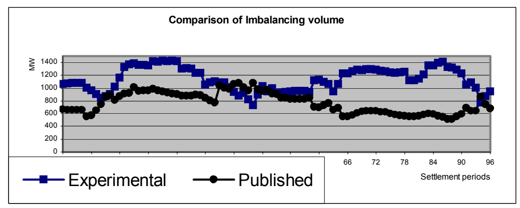

Figure 15: Comparison of the unbalancing volume

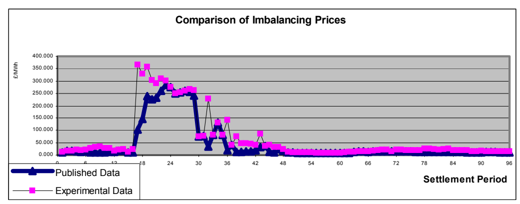

Figure 16: Comparison of the unbalancing prices

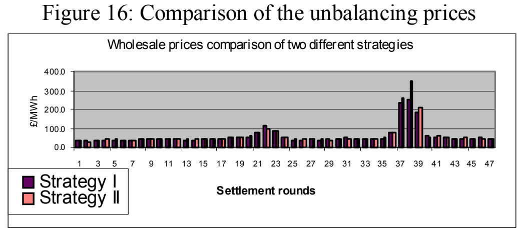

Figure 17: Comparison of wholesale prices

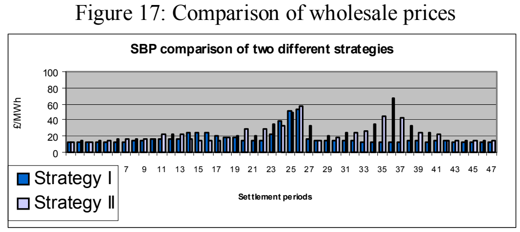

Figure 18: Comparison of SBP prices

Authorized licensed use limited to: UNIVERSITY OF GLASGOW. Downloaded on January 5, 2009 at 06:23 from IEEE Xplore. Restrictions apply.

6. CONCLUSIONS

A GA and its genotype and phonotype parameters have enabled intelligent modelling of the NETA electricity market. The ability of EC in including game theory allows gaming strategies of power generation firms to be well simulated and built into the model. The market manipulation and strategic trading behaviours made by market players can hence be analysed and predicted to a certain degree. Therefore, a hybrid approach combining the advantage of both game theory and evolutionary computing has been developed as intelligent support techniques for decision-making on electricity trading strategies under NETA.

Test results show that the model evolved is a helpful tool in developing competent strategies and that profits of generators with a gaming strategy are much greater than generators who trade independently. The model also reveals that

(1) When some generation companies adopt a cooperative strategy, the market prices are driven up to a level signigicantly higher than when no gaming is played.
(2) Fitness, percentage premium and overcontracting premium have shown that the profits of generators with a gaming strategy are much greater than generators who trade without.
(3) "Trigger price strategies" is proved to be a useful method of executing the agreement as the market clearing prices with management-enforcement are kept considerably high.
(4) On a non-natural oligopoly electricity market where the total supply exceeds total demand, the effort of finding a coalition among main generators to drive the market to an oligopoly setting can not achieve its original targets, because some main generators are always on the agreement.
(5) Manipulation on market prices can be accomplished when at least half of generation volume holders loyally carry out the agreement. An equilibrium trading state is kept on a balance prices level.

REFERENCES

[1] Martha McNeil Hamilton and Greg Schneider, Price Caps Have Questionable Record, Washington Post, May 31, 2001.
[2] Richard Perez-pena**,** Blackout Report Blames Ohio Utility, The New York Times. November 20, 2003.
[3] John M. Broder, California Power Failures Linked to Energy Companies, The New York Times. September 18, 2002.
[4] The new electricity trading arrangements, Ofgem DTI conclusions, document. U.K. Oct. 1999
[5] Paule Stephenson, Electricity market trading, Power Engineering Journal, 2001.
[6] Brian Saunders, NETA: a dramatic change, ELECTRA, December, 2001.
[7] The new electricity trading arrangements. OFGEM, London, http://www.ofgem.gov.uk/docs/reta3.pdf, July, 1999
[8] NGC incentives under NETA. OFGEM, U.K. http://www.ofgem.gov.uk/docs/ngcfeb.pdf, 04 2000
[9] Settlement Administration Agent User Requirements Specification. OFGEM, U.K., 06 2000
[10] Balancing Mechanism Reporting System. OFGEM, U.K. http://www.bmreports.com/bwx_reporting.htm
[11] Charles L. Cole, Microeconomics (New York: Harcourt Jovanovich, Inc., 2nd ed. 1995.
[12] H. S. Bierman, et al, Game theory with economic applications (New York: Addison-Wesley, Inc., 1998).
[13] The review of the first year of NETA. OFGEM, London, U.K. July 2002.
[14] C. McClay, The impact of NETA imbalance prices on contracting strategies for generation and demand, Power System Management and Control, 2002, Fifth International Conference on (Conf. Publ. No. 488), 2002.
[15] Charles L. Cole, Microeconomics (New York: Harcourt Jovanovich, Inc., 1983).
[16] D. Bunn, The Agent-Based Simulation—An Application to the New Electricity Trading Arrangements of England and Wales, IEEE Trans. Evol. Comp., Vol. 5, No. 5, Oct. 2001

Authorized licensed use limited to: UNIVERSITY OF GLASGOW. Downloaded on January 5, 2009 at 06:23 from IEEE Xplore. Restrictions apply.